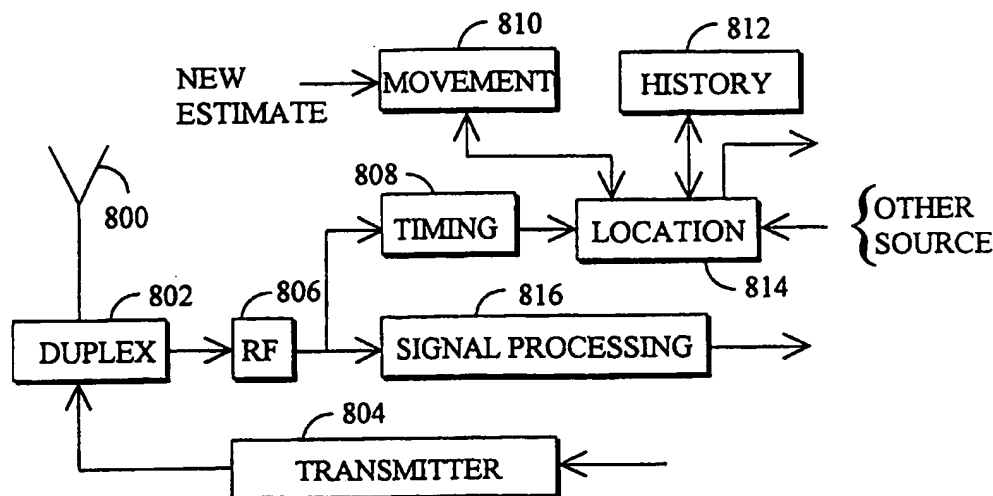




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<p>(21) International Application Number: PCT/FI99/00448</p> <p>(22) International Filing Date: 25 May 1999 (25.05.99)</p> <p>(30) Priority Data: 981192 28 May 1998 (28.05.98) FI</p> <p>(71) Applicant (for all designated States except US): NOKIA NETWORKS OY [FI/FI]; Keilalahdentie 4, FIN-02150 Espoo (FI).</p> <p>(72) Inventor; and (75) Inventor/Applicant (for US only): HELENIUS, Jyri [FI/FI]; Timpurinkuja 1 A 15, FIN-02600 Espoo (FI).</p> <p>(74) Agent: PATENTTITOIMISTO TEKNOLOGIS KOLSTER OY; c/o Kolster OY AB, Iso Roobertinkatu 23, P.O. Box 148, FIN-00121 Helsinki (FI).</p>	<p>(81) Designated States: AE, AL, AM, AT, AT (Utility model), AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, EE (Utility model), ES, FI, FI (Utility model), GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).</p> <p>Published In English translation (filed in Finnish). Without international search report and to be republished upon receipt of that report.</p>	

(54) Title: LOCATION METHOD AND RADIO SYSTEM



## (57) Abstract

The invention relates to a location method and a radio system implementing the location method. At least one previous measuring data item relating to the location of a mobile station is stored in a memory (812). A timing device (808) measures a new timing of the signals between the mobile station and at most two base stations. A location determination device (814) determines the current location estimate of the mobile station by means of the new timing and at least one previous measuring data item relating to the location of the mobile station. In addition, it is possible to utilize a travel estimate provided by a travel estimator (810), which travel estimate represents a travel possibly or probably made by the mobile station between the measuring instants.

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## LOCATION METHOD AND RADIO SYSTEM

### FIELD OF THE INVENTION

The invention relates to a location method employed in a radio system which comprises at least one base station and a mobile station.

- 5           The invention also relates to a radio system which comprises at least one mobile station and a base station and which is arranged to determine a location estimate of the mobile station.

### BACKGROUND OF THE INVENTION

- 10           One of the most common methods of determining the location of a mobile station is to measure the timing between the mobile station and at least three base stations, whereby the signal propagation time between the mobile station and each of the base stations is found out. The distance of the mobile station from the base stations can be represented as a circle about each base station, since in most cases the direction of the mobile station from the base stations is not known, and the radius of each circle represents the distance of the mobile station from the base station. All, at least three, circles have one common intersection, which is a location estimate of the mobile station. Known measuring methods used for mobile station location include TOA (Time Of Arrival) measuring and TDOA (Time Difference Of Arrival) measuring. US Patent 15 5,508,708, which is incorporated herein by reference, also discloses a solution to determine a location estimate of the mobile station, by means of at least three base stations, based on measuring the timing of the signals.

- 20           However, the radio systems have a drawback concerning these location methods, which results from the distance between the subscriber terminal and the base station, i.e. a near-far problem. In mobile station location this problem is also known as an audibility problem. A mobile station locating close to one base station cannot be heard by other base stations, and due to interfering transmission of the nearby base station, the mobile station cannot hear the other base stations. When the signal propagation time between the mobile station and at least three base stations cannot be measured, the location of the mobile station cannot be determined either in this manner. US Patent 30 5,508,708 attempts to reduce the audibility problem by using a so-called PUF (Power Up Function), by means of which transmission power is increased for the duration of location measuring. However, the increase in power increases interference in the radio system, which considerably decreases the capacity of 35

the radio system, and therefore it is not a suitable solution for the problem, if the locations of a plurality of mobile stations have to be estimated in the same area within a short period of time. The PUF function also increases power consumption of the mobile station and accelerates the battery discharge.

## 5 BRIEF DESCRIPTION OF THE INVENTION

The object of the invention is thus to provide a method and a radio system implementing the method to the effect that the above drawbacks can be eliminated. This is achieved with a method of the type described in the preamble, which is characterized in that, in order to determine a current location estimate of the mobile station, at least one previous measuring data item relating to the location of the mobile station is stored; new timing of signals between the mobile station and at most two base stations is measured; the current location estimate of the mobile station is determined by means of the new timing and at least one previous measuring data item relating to the location of the mobile station.

The radio system of the invention is characterized by comprising: a memory, in which is stored at least one location data item of the mobile station or a signal timing data item determining the location estimate of the mobile station; timing means for measuring the timing of the signal between the mobile station and at least one base station; location calculating means for determining the current location estimate of the mobile station by means of the new timing and at least one previous location data item or the timing data item determining the location estimate.

Several advantages are achieved with the method and system of the invention. The audibility problem alleviates or is eliminated altogether. There is no need for three base stations to determine the location estimate of the mobile station, but in many cases, the location estimate of the mobile station can be determined with two base stations, and in favourable conditions even with one base station.

## 30 BRIEF DESCRIPTION OF THE DRAWINGS

In the following, the invention will be described in greater detail in connection with preferred embodiments with reference to the attached drawings, wherein

Figure 1 shows a radio system,

Figure 2 shows location determination of a mobile station by means of two base stations,

Figure 3 shows location determination of a mobile station by means of two base stations,

5        Figure 4 shows location determination of a mobile station, the transmission of the base station being sectorized,

Figure 5 shows location determination of a mobile station by means of one base station,

10       Figure 6 shows location determination of a mobile station by means of location area data of the mobile station,

Figure 7 shows location determination of a mobile station by means of a Kalman filter,

Figure 8A is a block diagram of a mobile station,

Figure 8B is a block diagram of a base station,

15       Figure 9 is a block diagram of a transceiver, and

Figure 10 is a block diagram of a transceiver.

#### DETAILED DESCRIPTION OF THE INVENTION

The solution in accordance with the invention is particularly applicable to the CDMA radio system, without restricting thereto, however.

20       Figure 1 shows a radio system, which comprises a mobile station 100, base stations 102 to 106 and a base station controller 108. The mobile station 100, which is preferably a mobile telephone, communicates with the base station 102, for instance. Base stations 104 and 106 are neighbouring base stations of the base station 102. The base stations 102 to 106 preferably  
25       have a common base station controller 108, from which there is a further connection, for instance via a mobile services switching centre (not shown in Figure 1), to other parts of the mobile telephone network and to other telephone networks. The network part of the radio system is determined to comprise all other parts of the radio system than the mobile stations 100.

30       For measuring the location of the mobile station, or more precisely the location estimate, a signal propagation time between the mobile station and at least one base station is needed. The signal propagation time between the mobile station and the base station can be measured by the base station or the mobile station in a known manner. Timing measurement of the mobile  
35       station signal will be studied in the following. First the mobile station measures

a time of arrival TOA of the signals transmitted by each base station. Time differences of arrival TDOA between the base station signals or an observed time difference OTD can be formed by calculating the differences of the times of arrival TOA of the base stations. In the CDMA system, the time of arrival  
5 can be determined by utilizing the synchronization of a spreading code. When a specific spreading code chip (chip is a spreading code bit) in the mobile station occurs at a time instant  $t_1$  and the same chip in the base station occurs at a time instant  $t_2$ , the signal propagation time between the mobile station and the base station is  $t_2$  less  $t_1$ . The mobile station measures the time  $t_1$  and the  
10 base station measures the time  $t_2$ . In the solution in accordance with the invention, the clock need not be synchronized with the base station clocks. When the mobile station transmits a so-called round-trip signal to a base station and the base station responds to said signal, the influence of the time difference between the mobile station and the base station can be eliminated. If  
15 the base station transmissions are not synchronized and the time differences between the base stations are not known, the round-trip measuring has to be performed with all those base stations whose signal timing the mobile station measures. In a synchronized network, or if the time differences between the base stations are known, the round-trip signal is not needed when using the  
20 TDOA method based on time differences for determining the location. In the TOA method based on propagation time delays the round-trip signal is thus only needed to a serving base station.

While the mobile station transmits a signal, the base stations can measure the propagation time and/or the difference in propagation times  
25 (TDOA; OTD) of the signal transmitted by the mobile station in a known manner.

The signal timing measurement involves an error  $T_e$ , which causes an error in the distance measurement in the order of  $E = T_e c$ , where  $c$  is the propagation rate of electromagnetic radiation. For instance, if the timing error  
30  $T_e$  is 25 ns, the corresponding error in the distance measurement is about 15 m. The measurements in accordance with the invention are preferably carried out on so-called lines of sight. If there is no line of sight, the determined location estimate of the mobile station may deviate up to hundreds of metres from the true location in a hilly terrain, and also in an urban area typically several tens  
35 of metres.

In the solution in accordance with the invention, the location estimate of the mobile station is determined in at least one measuring, by means of at most two base stations, utilizing at least one previous location-related data item of the mobile station. The location-related data item can be a previously determined location estimate of the mobile station or a signal timing data item measured for the previous location estimate. These location-related data can be stored in the mobile station or in a unit in the fixed network part. Since data to be stored accumulate all the time, and storing cannot be continued endlessly, it is preferable that stored data items are reduced, when the memory capacity is running out or the maximum number of data items to be stored is achieved. Since the inventive solution requires the memory to comprise data items starting from the moment when the position of the mobile station could last have been estimated, the stored data items can be reduced, if need be, for instance such that every second data item is deleted from the memory when more memory capacity is needed. However, it is not advisable to delete the last formed, location-related data item, unless the data item is clearly erroneous. Moreover, the storing of data needed for location can be discontinued, when the mobile station is stationary. The movement of the mobile station can be determined as a change in the mobile station location at different measuring instants. If the location estimate of the mobile station, the TOA or TDOA measuring result does not change substantially in successive measurements, it can be assumed that the mobile station is stationary. In particular, if the difference between the successive measurements is minor and the sign of the difference varies, it is probable that the mobile station has stopped moving. In the inventive solution, the movement of the mobile station and particularly its speed can be determined by known methods of measuring movement, independent of the invention.

Figure 2 illustrates a situation, in which the true location or a location estimate of the mobile station 204 is known at a given instant of time T1. The locations of the mobile station 204 on measuring occasions preceding the measuring instant T1 are indicated with the letters X. In a common case, the location estimate of the mobile station 204 could have been determined at the instant of time T1 by any known mobile station location method. In the solution in accordance with the invention, the location estimate of the mobile station 204 is generally determined by means of one or more base stations 200, 202. In a prior art solution, the location estimate of the mobile station 204 is deter-

mined at the instant of time T1 by means of three or more base stations. At the subsequent instant of time T0, the location estimate of the mobile station 204 is determined by the method of the invention utilizing at most two base stations. It is known on the basis of the signal timing that, at the measuring instant T0, the mobile station 204 is located at a distance R1 from the base station 200 and at a distance R2 from the base station 202. Consequently, the mobile station 204 must be located at either one of the intersections 206 and 208 of the circles with radii R1 and R2. In the inventive solution, the highest speed of the mobile station 204 is utilized by assessing how far from the location of the measuring instant T1 the mobile station 204 can move between the measuring instants T1 and T0. Said distance, which is here defined as a travel estimate, can be indicated with the letter D, and since it is not known in this example, in which direction the mobile station 204 has moved, the new location of the mobile station 204 must be inside the circle having the radius D. The travel estimate is an estimate on the travel possibly or probably made by the mobile station between the measuring instants. Thus these three circles having the radii R1, R2 and D determine the intersection 208 to be a new location estimate of the mobile station 204. If the mobile station is assumed to continue its travel with a high probability in a given direction, the travel estimate can be depicted by other means than a circle. The shape of the travel estimate can be an ellipse, for instance, at one center of gravity of which the mobile station 204 is located at the instant of time T1. Moreover, more than one locations of the mobile station 204 or the location-related signal timing prior to the measuring instant T0 can be utilized when determining a new location estimate of the mobile station 204 at the instant of time T0. All measured distances R1, R2 and D involve a measuring error, but for the sake of clarity, the errors have not been shown in the figures (only Figure 5 shows the error limits of the radius R1).

In the inventive solution, the speed of the mobile station 204 can be estimated at each measuring instant by using a map over the location area, since in a given environment the mobile station tends to move at given speeds. For instance, speeds in urban areas are typically less than 50 km/h, even though the fastest possible means would be used for moving. In a region between densely populated areas, it is common to move a lot faster than 50 km/h. In addition to or in place of the map, the speed of the mobile station can also be estimated by utilizing the information on what kind of travel routes



there are in the location area of the mobile station. When the mobile station can be localized to a road, railway, or for instance, to a waterway, it is also easy to estimate the speed of the mobile station on said travel route. Speed can also be estimated by statistical methods, in which case advance measurements on the speeds of the mobile stations and dispersion of the speeds have been carried out in each area to be measured. Hence, it can be estimated that the speed of the mobile station is, for instance, the average speed in the area and a travel estimate can be formed thereby. Figure 6 shows an example of utilizing the information on the mobile station location for determining a location estimate of the mobile station.

Figure 3 illustrates a situation, in which the mobile station 304 moves so fast that, at the measuring instant  $T_0$ , the intersections 306 and 308 of the base station 300 and 302 circles with radii  $R_1$  and  $R_2$  are within a circle with radius  $D$  belonging to the instant of time  $T_1$ . In the solution of the invention, a point which is in the middle of the overlapping areas of the circles having the radii  $R_1$  and  $R_2$  is in this case determined as the location estimate of the mobile station, whereby the location estimate error is substantially minimized. To be precise, the location estimate of the mobile station 304 is the middle point of the line connecting the intersections of the circles.

In the solution of the invention, in addition to a new measuring instant and that preceding the new one, it is also possible to consider other factors that have a longer effect on the location, speed and travel direction of the mobile station, whereby the location determination improves. This inventive feature will be reverted to in connection with Figure 7.

Figure 4 illustrates a situation, in which the base station 400 transmits or receives signals in a sectorized manner. The mobile station 404 is at a distance  $R_1$  in a sector of the base station 400. The mobile station 404 is also simultaneously at a distance  $R_2$  from the base station 402. Thus the sector defined by the antenna beam of the base station 400 and the omnidirectional antenna beam of the base station 402 have only one intersection. In the inventive solution, the location estimate of the mobile station 404 is determined at the intersection 406.

Figure 5 illustrates an inventive solution employing only one base station 500 for the location of the mobile station 502. The distance of the mobile station 502 from the base station 500 is determined to equal the radius  $R_1$  on the basis of the timing of the signals. Said distance  $R_1$  involves inaccuracy,

which is indicated with the letter E. At the measuring instant T1 preceding the new measuring instant T0, a circular travel estimate having a radius D is associated with the mobile station 502. Consequently, the new location area of the mobile station 502 will be a curved zone 504, which is the common intersectional area of the travel estimate circle and the inaccuracy E in the distance R1. In the inventive solution, any one of the points of the zone 504, for instance the middle point of the zone, is determined as the location estimate of the mobile station 502. Alternatively, a point in the overlapping areas of the circles having the radii R1 and D can be determined as the location estimate of the mobile station, at which point the maximum error in the location is minimized. Said point is approximately the middle point of the line connecting the intersections of the circles having the radii R1 and D. When the signal timing of the mobile station and of only one base station (base station 500) can be measured, in the inventive solution, the location of the base station (base station 500) included in the measuring can be determined as the location estimate of the mobile station 204.

Figure 6 shows a situation, in which the mobile station's location area data are utilized for determining the location. When the mobile station moves along a known route 604, such as a road, the location estimate 606 of the mobile station can be determined by means of two base stations 600 and the signal timing 602, as clearly appears from Figure 6. The other intersection of the circles cannot be the location of the mobile station, since it is not on the route 604, where the mobile station was already located in accordance with a plurality of previous location estimates.

Figure 7 illustrates determination of the location estimate of the mobile station 704 by means of two base stations 700 and 702 when using Kalman filtering (referring herein in particular to the Extended Kalman Filter), or the like, for the measuring data. It is substantial in this solution of the invention that only restricted changes of speed and travel direction of the mobile station 704 are allowed, i.e. sudden changes of speed or sharp turns are not accepted. A transition that is not accepted is indicated by a broken arrow. On these conditions, the location estimate of the mobile station 704 approximately follows the path formed by the intersections of two circles. If the intersections of the two circles are sufficiently far from each other, the location estimate is highly likely to follow the correct path of the two alternative paths formed by the intersections.

Let us take a closer look at the operation of the Extended Kalman Filter in the inventive solution. The operation of the Extended Kalman Filter is described in greater detail in the publication by S. M. Kay, *Fundamentals of Statistical Signal Processing, Estimation Theory*, pp. 419 to 477, PTR Prentice Hall, 1993, which is incorporated herein as reference. The method is based on the fact that the movement and distance measurements of the mobile station are assumed to have the formula:

$$\begin{aligned}
 x(k) &= x(k-1) + v_x(k-1)\Delta \\
 y(k) &= y(k-1) + v_y(k-1)\Delta \\
 v_x(k) &= v_x(k-1) + \varepsilon_x \\
 v_y(k) &= v_y(k-1) + \varepsilon_y \\
 r_i(k) &= \sqrt{(x_i - x(k))^2 + (y_i - y(k))^2} + \varepsilon_i, \text{ where}
 \end{aligned}$$

$x(k)$ ,  $y(k)$  are the  $x$  and  $y$  coordinates of the mobile station location at an instant  $k\Delta$ ,  $k$  is an iteration index depending on the instant of time,  $v_x(k)$ ,  $v_y(k)$  are speeds of the mobile station in the direction of the coordinates  $x$  and  $y$ ,  $\Delta$  is an interval between the measuring instants,  $r_i(k)$  is an estimate on the distance between the mobile station and the base station  $i$  calculated on the basis of TOA measuring,  $\varepsilon_x$  represents change of speed in time  $\Delta$  in the direction of the coordinate  $x$ ,  $\varepsilon_y$  represents change of speed in time  $\Delta$  in the direction of the coordinate  $y$  and  $\varepsilon_i$  is a measuring error of distance, the range of which is indicated by  $E$  in Figure 5. The speeds in the formula correspond to the travel estimate determined above. To determine the location estimate of the mobile station, the extended Kalman filtering also requires a cross-correlation matrix  $Q$  of speed, which has the formula:

$$Q = \begin{bmatrix} \sigma_x^2 & \sigma_{xy} \\ \sigma_{xy} & \sigma_y^2 \end{bmatrix}, \text{ where}$$

$\sigma_x$  and  $\sigma_y$  are variances of speed errors  $\varepsilon_x$  and  $\varepsilon_y$  and  $\sigma_{xy}$  is a cross correlation of the speed errors  $\varepsilon_x$  and  $\varepsilon_y$ . The variances describe how much each speed component may change during an iteration cycle. The greater the variances, the greater the assumed change of speed. The values in the cross-correlation matrix  $Q$  of speed errors can be calculated statistically, if applicable measuring data is available. A cross-correlation matrix  $C$  of measuring errors of distance can thus be formed as follows:

10

$$C = \begin{bmatrix} \sigma_1^2 & \sigma_{12}^2 & \cdots & \sigma_{1N}^2 \\ \sigma_{12}^2 & \sigma_2^2 & \cdots & \\ \vdots & & \ddots & \\ \sigma_{1N}^2 & & \cdots & \sigma_N^2 \end{bmatrix}, \text{ where}$$

$\sigma_i$  is a variance of a distance measurement error  $\varepsilon_i$  and  $\sigma_{ij}$  is a cross correlation of two different measuring errors of distance  $\varepsilon_i$  and  $\varepsilon_j$ . The matrix C can be used as an initial value of a matrix M of the Kalman Filter. The matrix C values  
 5 in various ranges can be calculated statistically, if suitable measuring data is available. When the variances of measuring errors grow, the location estimates calculated by the Extended Kalman Filter will be more and more based on the model of the filter and less on the measurements.

In the solution of the invention, solutions only employing a simple  
 10 travel estimate circle and extended Kalman filtering can be combined into a solution which is similar to extended Kalman filtering but simpler. In this case, in the inventive solution the speed and direction of the mobile station are estimated from history data, i.e. from previous location estimate data and/or from signal timing measurements. When the mobile station's location estimate, speed and direction at the instant T1 are known, it is possible to provide an estimate  
 15 on the location of the mobile station at a subsequent measuring instant T0. At the instant T0, the timing of signals between the mobile station and the base station are measured, on the basis of said timings are determined the mobile station's preliminary location estimates, which are two in number, if the measuring included only two base stations. Of these two preliminary location estimates the one that is closer to the location estimated at the instant T1 is determined as the actual location estimate in the inventive solution.

Figure 8A is a transceiver block diagram illustrating a mobile station. Here the mobile station determines its own location estimate. The mobile  
 25 station hears signals of at most two base stations for new location measuring (previous signal measurements could have been performed by using three or more base stations). The mobile station receives and transmits through an antenna 800. Transmission and reception are possible through the same antenna 800, since a transmitter block 804 and receiver blocks 806 to 816 are separated with a duplex block 802 in a known manner. When receiving a signal, the signal propagates from the antenna 800 via the duplex block 802 to an RF block 806, where the signal is converted from a radio frequency to a base band in accordance with the prior art. The baseband signal is also transformed  
 30

to digital. The digital signal propagates to a signal processing block 816 of the receiver, which block is irrelevant to the invention and where demodulating, channel decoding, de-interleaving and so on are performed on the signal, for instance. The digital signal also propagates to a block 808, which is relevant to the invention, and where the signal timing is determined, by means of which timing the mobile station knows how far the mobile station is from the base station that transmitted the signal. Information on the signal timing or the distance from the base station is transferred to a location calculation block 814, where to the travel estimate from the block 810 is also transferred. Stored data on previous locations of the mobile station or signal timings from the block 812 can also be supplied to the location calculation block 814. For determining the mobile station location, the location data on the base stations that are included in determining the location estimate of the mobile station are also needed. In an asynchronous radio system, where round-trip signals are not used, the data on timing differences of the base station clocks are also needed. The base stations transmit these data to the mobile station, when necessary, in prior art signalling.

Figure 8B depicts a base station, which measures the timing of the signal transmitted by the mobile station and thus determines the distance of the mobile station from the base station. The block diagram is very similar to that of Figure 8A. When the base station has the travel estimate of the mobile station in store in the block 810, the base station can determine the location estimate of the mobile station. Signal timing data or location data of other base stations, which preferably come to the base station through a fixed network part, can be fed to the location calculation block 814, when necessary. The measuring base station needs location data on the base stations that are included in determining the location estimate of the mobile station. In addition, the timing differences of the base stations in the radio system have to be signalled to the measuring base station. The base station receives these data in prior art signalling between other base stations.

Figure 9 shows a mobile station block diagram, which comprises an antenna 900, a duplex filter 902, radio frequency parts 906, a signal processing block 908, a timing block 910 and a transmitter block 904. The mobile station measures the timing of the signal coming from the base station in the block 910 and transmits the timing data to the base station, which determines the location estimate of the mobile station, or the base station forwards the

timing data to a base station controller, for instance, or to some other unit of the fixed network part for determining the location estimate of the mobile station. In principle, Figure 9 can also be a block diagram of the base station, whereby the base station measures, by means of the timing block 910, the timing of the signal transmitted by the mobile station and transmits the timing data to the mobile station for determination of the location estimate.

Figure 10 illustrates a situation, in which the base station determines the location estimate of the mobile station, after the mobile station has measured the timing of the received signals and transmitted said timing data to the base station. The base station receives the measuring data signal of the mobile station with the antenna 1000, wherefrom the signal propagates through a duplex filter 1002 to a radio frequency block 1006. After the radio frequency block 1006, the baseband signal typically passes to a digital signal processing block 1008, where the signal information is detected and the timing data are transferred to the location calculation block 1010, to which are also supplied the travel estimate of the mobile station from the block 1012, and if necessary, the data on previous location estimates or signal timings from the block 1014. In the inventive solution, the block entity can also be in the base station controller or some other unit of the fixed network part. The measuring base station needs location information on those base stations that are included in determining the mobile station location estimate. In addition, the timing differences of the base stations in the radio system have to be signalled to the measuring base station. The base station receives these data in prior art signalling between other base stations. Transmission from the base station to the mobile station is performed by means of the transmitter block 1004 through the duplex filter 1002 and the antenna 1000.

The solutions of the invention can be implemented, particularly as far as digital signal processing is concerned, by ASIC (Application-Specific Integrated Circuit) or VLSI (Very Large Scale Integration) circuits, for instance. The operations to be performed are preferably implemented as software based on microprocessor techniques.

Even though the invention is described in the above with reference to the examples of the attached drawings, it is obvious that the invention is not restricted thereto, but it can be modified in a variety of ways within the scope of the inventive idea disclosed in the attached claims.

## CLAIMS

1. A location method employed in a radio system which comprises at least one base station (102 to 106, 200, 202, 300, 302, 400, 402, 500, 600, 602, 700, 702) and a mobile station (100, 204, 304, 404, 502, 704), **characterized** in that in order to determine a current location estimate of the mobile station (100, 204, 304, 404, 502, 702):

at least one previous measuring data item relating to the location of the mobile station (100, 204, 304, 404, 502, 704) is stored;

new timing of signals between the mobile station (100, 204, 304, 404, 502, 704) and at most two base stations (102 to 106, 200, 202, 300, 302, 400, 402, 500, 600, 602, 700, 702) is measured;

the current location estimate of the mobile station (100, 204, 304, 404, 502, 704) is determined by means of the new timing and at least one previous measuring data item relating to the location of the mobile station (100, 204, 304, 404, 502, 704).

2. A method as claimed in claim 1, **characterized** by having the disposal of a travel estimate estimating the movement of the mobile station (100, 204, 304, 404, 502, 704), which estimate determines the travel possibly or probably made by the mobile station (100, 204, 304, 404, 502, 704) between the measuring instants, and

the current location estimate of the mobile station (100, 204, 304, 404, 502, 704) is determined by means of the new timing, travel estimate and at least one previous measuring data item relating to the location of the mobile station (100, 204, 304, 404, 502, 704).

3. A method as claimed in claim 1, **characterized** in that the previous measuring data item relating to the location of the mobile station (100, 204, 304, 404, 502, 704) is based on the signal timing between at least three base stations (102 to 106, 200, 202, 300, 302, 400, 402, 500, 600, 602, 700, 702) and the mobile station (100, 204, 304, 404, 502, 704).

4. A method as claimed in claim 1, **characterized** in that the previous measuring data item relating to the location of the mobile station (100, 204, 304, 404, 502, 704) is based on the signal timing between at most two base stations (102 to 106, 200, 202, 300, 302, 400, 402, 500, 600, 602, 700, 702) and the mobile station (100, 204, 304, 404, 502, 704).

5. A method as claimed in claim 1, **characterized** in that a new timing of the signal between the mobile station (100, 204, 304, 404, 502, 704) and the base station (102 to 106, 200, 202, 300, 302, 400, 402, 500, 600, 602, 700, 702) is measured for determining the location estimate of the mobile station (100, 204, 304, 404, 502, 704).

6. A method as claimed in claim 2, **characterized** in that the travel estimate of the mobile station (100, 204, 304, 404, 502, 704) determines the longest possible distance of the mobile station (100, 204, 304, 404, 502, 704) between the new location estimate and that preceding the new one.

7. A method as claimed in claim 2, **characterized** in that the travel estimate of the mobile station (100, 204, 304, 404, 502, 704) is formed by utilizing a map over the location area of the mobile station (100, 204, 304, 404, 502, 704), by means of which map the highest possible speed of the mobile station (100, 204, 304, 404, 502, 704) is estimated.

8. A method as claimed in claim 2, **characterized** in that the travel estimate of the mobile station (100, 204, 304, 404, 502, 704) is formed by utilizing preformed speed-related statistical data on the area where the mobile station is located.

9. A method as claimed in claim 2, **characterized** in that the travel estimate of the mobile station (100, 204, 304, 404, 502, 704) is formed by utilizing the speed data on roads, railways, waterways and/or the like of the location area of the mobile station (100, 204, 304, 404, 502, 704).

10. A method as claimed in claim 2, **characterized** in that the travel estimate comprises the data on the direction and magnitude of the movement of the mobile station (100, 204, 304, 404, 502, 704).

11. A method as claimed in claim 10, **characterized** in that the previous measuring data being signal timing data, the location estimate of the mobile station (100, 204, 304, 404, 502, 704) is determined iteratively at each measuring time by using Extended Kalman filtering or the like in the determination of the location estimate of the mobile station (100, 204, 304, 404, 502, 704).

12. A method as claimed in claim 1, **characterized** in that the mobile station determines its own location estimate.

13. A method as claimed in claim 1, **characterized** in that the location estimate of the mobile station (100, 204, 304, 404, 502, 704) is determined in the fixed network part of the radio system.



14. A method as claimed in claim 1, **characterized** in that when the base station (102 to 106, 200, 202, 300, 302, 400, 402, 500, 600, 602, 700, 702) included in the measuring operates in a sectorized manner, the location estimate of the mobile station (100, 204, 304, 404, 502, 704) is determined by sectors.

15. A method as claimed in claim 2, **characterized** in that when using two base stations for the location estimate determination of the mobile station (100, 204, 304, 404, 502, 704), whereby there are two possible location points for the mobile station (100, 204, 304, 404, 502, 704), and the travel estimate comprising both possible location points (206, 208, 306, 308), the middle point of the possible location points is determined as the location estimate of the mobile station (100, 204, 304, 404, 502, 704).

16. A method as claimed in claim 1, **characterized** in that new data relating to the location estimate determination of the mobile station (100, 204, 304, 404, 502, 704) are continuously stored and when the amount of stored data exceeds a predetermined maximum, some of the data are deleted such that data stored at different times are evenly subjected to deletion.

17. A method as claimed in claim 1, **characterized** in that when the new timing and at least one previous timing, or the current location estimate and at least one previous location estimate, deviate substantially from one another only within allowed error limits, the mobile station is determined as stationary and the storing of data needed for the location estimate determination is discontinued for the duration of immobility.

18. A method as claimed in claim 2, **characterized** in that when using one base station for the location estimate determination of the mobile station (100, 204, 304, 404, 502, 704), whereby the location area of the mobile station (100, 204, 304, 404, 502, 704) is a zone (504) within the range of the travel estimate because of a measuring error (E), any one point of the zone (504) or the point minimizing the largest measuring error of the location is determined as the location estimate of the mobile station (100, 204, 304, 404, 502, 704).

19. A method as claimed in claim 1, **characterized** in that when determining the location of the mobile station (100, 204, 304, 404, 502, 704) by means of one base station (102 to 106, 200, 202, 300, 302, 400, 402, 500, 600, 602, 700, 702), the location of the base station (102 to 106, 200,

202, 300, 302, 400, 402, 500, 600, 602, 700, 702) is determined as the location estimate of the mobile station.

20. A radio system which comprises at least one mobile station (100, 204, 304, 404, 502, 704) and a base station (102 to 106, 200, 202, 300, 302, 400, 402, 500, 600, 602, 700, 702) and which is arranged to determine a location estimate of the mobile station (100, 204, 304, 502, 704), **characterized** by comprising

a memory (812, 1014), in which is stored at least one location data item of the mobile station (100, 204, 304, 404, 502, 704) or a signal timing data item determining the location estimate of the mobile station (100, 204, 304, 404, 502, 704),

timing means (808, 910) for measuring the timing of the signal between the mobile station (100, 204, 304, 404, 502, 704) and at least one base station (102 to 106, 200, 202, 300, 302, 400, 402, 500, 600, 602, 700, 702),

location calculating means (814, 1010) for determining the current location estimate of the mobile station (100, 204, 304, 404, 502, 704) by means of the new timing and at least one previous location data item or the timing data determining the location estimate.

21. A radio system as claimed in claim 20, **characterized** by comprising

a travel estimator (810, 1012), which is arranged to determine the travel possibly or probably made by the mobile station (100, 204, 304, 404, 502, 704) between the measuring instants, i.e. the travel estimate, and

location calculating means (814, 1010) for determining the current location estimate of the mobile station (100, 204, 304, 404, 502, 704) by means of the new timing, travel estimate and at least one previous location data item or the timing data determining the location estimate.

22. A radio system as claimed in claim 20, **characterized** by being arranged to measure the previous measuring data relating to the location of the mobile station (100, 204, 304, 404, 502, 704) by means of the timing of signals between at least three base stations (102 to 106, 200, 202, 300, 302, 400, 402, 500, 600, 602, 700, 702) and the mobile station (100, 204, 304, 404, 502, 704).

23. A radio system as claimed in claim 20, **characterized** by being arranged to measure the previous measuring data relating to the location of the mobile station (100, 204, 304, 404, 502, 704) by means of the tim-

ing of signals between at most two base stations (102 to 106, 200, 202, 300, 302, 400, 402, 500, 600, 602, 700, 702) and the mobile station (100, 204, 304, 404, 502, 704).

24. A radio system as claimed in claim 20, **characterized** in  
5 that the timing means (808, 910) are arranged to measure the new timing of the signal between the mobile station (100, 204, 304, 404, 502, 704) and one base station (102 to 106, 200, 202, 300, 302, 400, 402, 500, 600, 602, 700, 702) for determining the current location estimate of the mobile station (100, 204, 304, 404, 502, 704).

10 25. A radio system as claimed in claim 21, **characterized** in that the travel estimator (810, 1012) is arranged to determine the mobile station's (100, 204, 304, 404, 502, 704) travel estimate, which is the mobile station's longest possible distance between the new location estimate and that preceding the new one.

15 26. A radio system as claimed in claim 21, **characterized** in that the travel estimate (810, 1012) is arranged to form the travel estimate of the mobile station (100, 204, 304, 404, 502, 704) by utilizing a map over the location area of the mobile station (100, 204, 304, 404, 502, 704) by means of which map it is possible to estimate the highest possible speed of the mobile  
20 station (100, 204, 304, 404, 502, 704).

27. A radio system as claimed in claim 21, **characterized** in that the travel estimator (810, 1012) is arranged to form the travel estimate of the mobile station (100, 204, 304, 404, 502, 704) by utilizing preformed speed-related statistical data on the area where the mobile station (100, 204, 304, 404, 502, 704) is located.  
25

28. A radio system as claimed in claim 21, **characterized** in that the travel estimator (810, 1012) is arranged to form the travel estimate of the mobile station (100, 204, 304, 404, 502, 704) by utilizing speed data on roads, railways, waterways and the like of the location area of the mobile station (100, 204, 304, 404, 502, 704).  
30

29. A radio system as claimed in claim 21, **characterized** in that the travel estimate of the travel estimator (810, 1012) comprises data on the direction and magnitude of the movement of the mobile station (100, 204, 304, 404, 502, 704).  
35

30. A radio system as claimed in claim 29, **characterized** in that the previous measuring data being signal timing data the location calcu-

lating means (814, 1010) is arranged to determine the location estimate of the mobile station (100, 204, 304, 404, 502, 704) iteratively at each measuring time by using Extended Kalman filtering or the like when determining the location estimate of the mobile station (100, 204, 304, 404, 502, 704).

5           31. A radio system as claimed in claim 20, **characterized** in that the mobile station is arranged to determine its own location estimate.

32. A radio system as claimed in claim 20, **characterized** in that the fixed network part of the radio system is arranged to determine the location estimate of the mobile station (100, 204, 304, 404, 502, 704).

10           33. A radio system as claimed in claim 20, **characterized** in that when the base station (102 to 106, 200, 202, 300, 302, 400, 402, 500, 600, 602, 700, 702) included in the measuring operates in a sectorized manner, the location calculating means (814, 1010) are arranged to determine the location estimate of the mobile station (100, 204, 304, 404, 502, 704) by sectors.  
15

34. A radio system as claimed in claim 21, **characterized** in that when using two base stations for the location estimate determination of the mobile station (100, 204, 304, 404, 502, 704), whereby there are two possible location points (206, 208, 306, 308) for the mobile station (100, 204, 304, 404, 502, 704), and the travel estimate comprising both possible location points, the location calculating means (814, 1010) are arranged to determine the middle point of the possible location points as the location estimate of the mobile station (100, 204, 304, 40, 502, 704).  
20

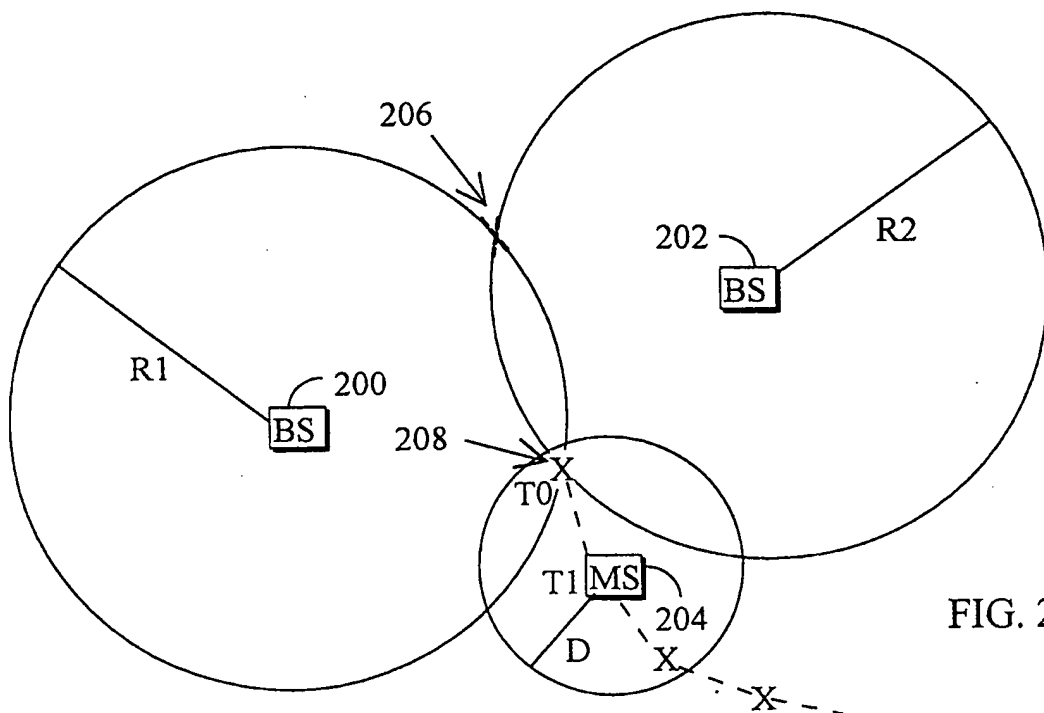
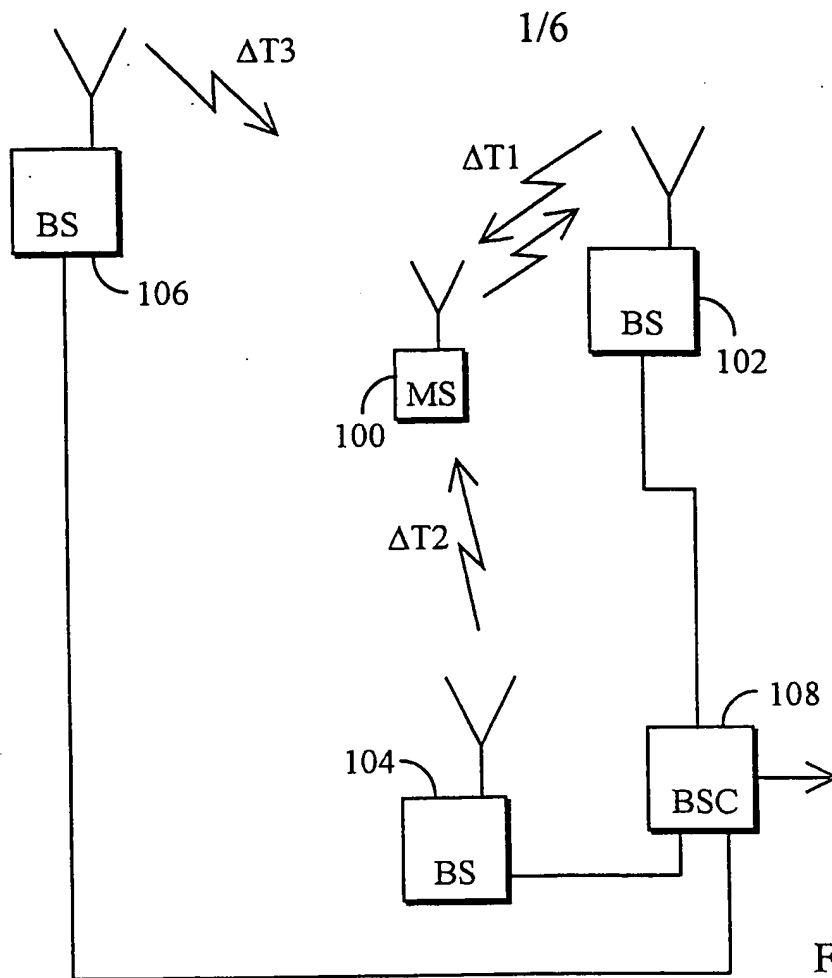
35. A radio system as claimed in claim 21, **characterized** in that when using one base station for the location estimate determination of the mobile station (100, 204, 304, 404, 502, 704), whereby the location area of the mobile station (100, 204, 304, 404, 502, 704) is the zone (504) within the range of the travel estimate the location calculating means (814, 1010) are arranged to determine any one point of the zone (504) or a point minimizing the largest measuring error of the location as the location estimate of the mobile station (100, 204, 304, 404, 502, 704).  
30

36. A radio system as claimed in claim 20, **characterized** in that the memory (812, 1014) is arranged to continuously store new data relating to the location estimate determination of the mobile station (100, 204, 304, 404, 502, 704) and the amount of stored data exceeding the predetermined  
35

maximum, the memory (812, 1014) is arranged to delete some of the data such that data stored at different times are evenly subjected to deletion.

37. A radio system as claimed in claim 20, **characterized** in that when the new timing and at least one previous timing, or the current location estimate and at least one previous location estimate, deviate substantially from one another only within allowed error limits, the location calculating means (814, 1010) are arranged to determine the mobile station (100, 204, 304, 404, 502, 704) as stationary and the location calculating means (814, 1010) are arranged to discontinue the storing of data needed for the location estimate determination for the duration of immobility.

38. A radio system as claimed in claim 20, **characterized** in that when determining the location of the mobile station (100, 204, 304, 404, 502, 704) by means of one base station (102 to 106, 200, 202, 300, 302, 400, 402, 500, 600, 602, 700, 702), the location calculating means (814, 1010) are arranged to determine the location of the base station (102 to 106, 200, 202, 300, 302, 400, 402, 500, 600, 602, 700, 702) as the location estimate of the mobile station (102 to 106).



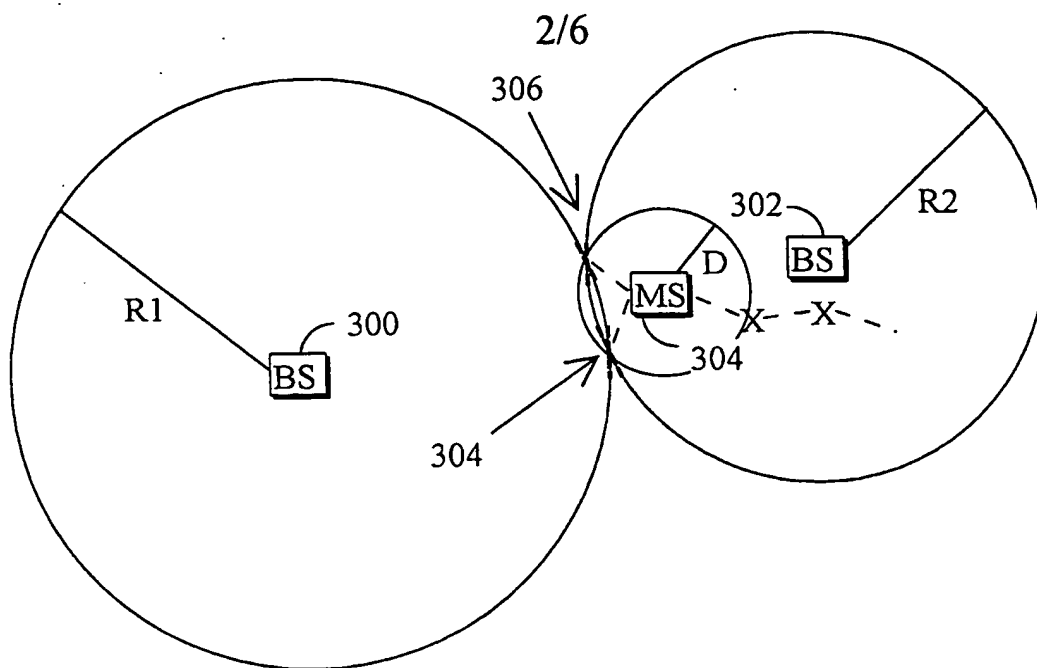


FIG. 3

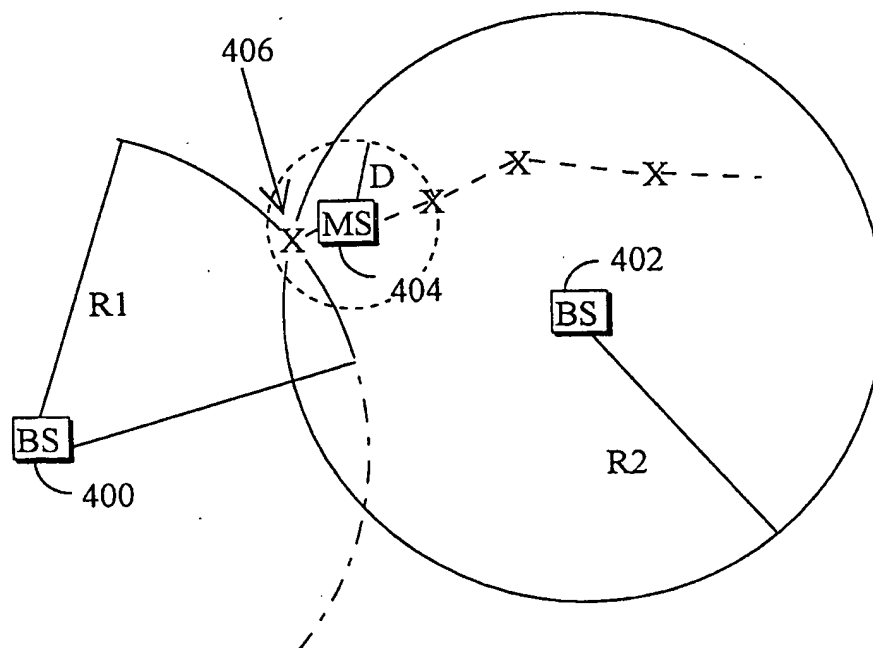


FIG. 4

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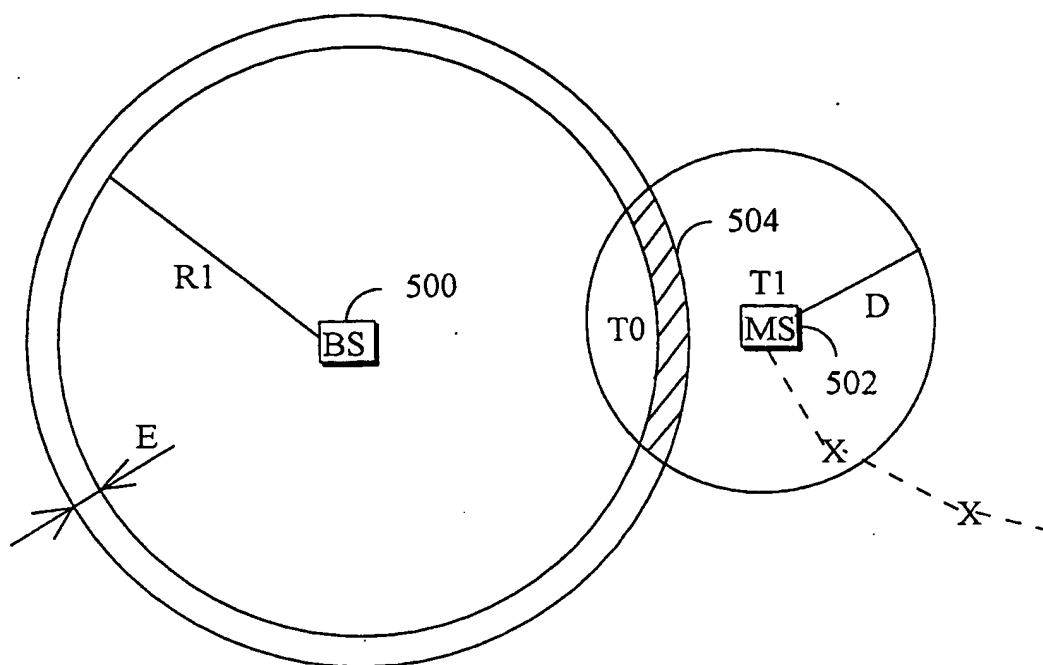


FIG. 5

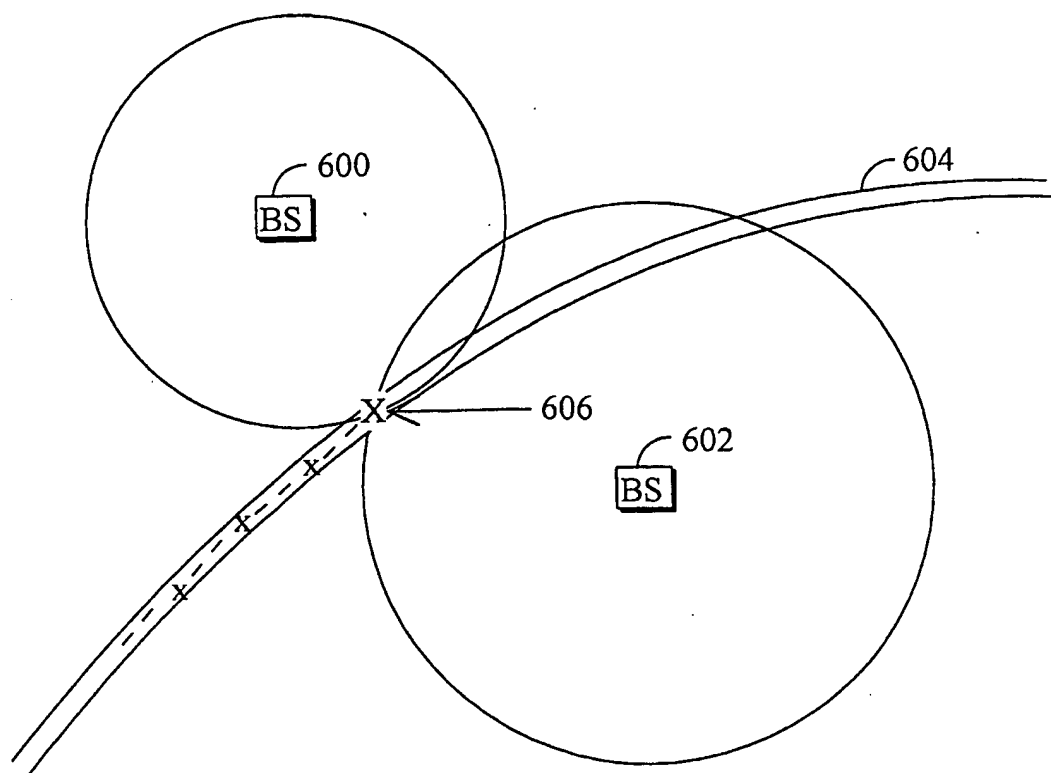


FIG. 6



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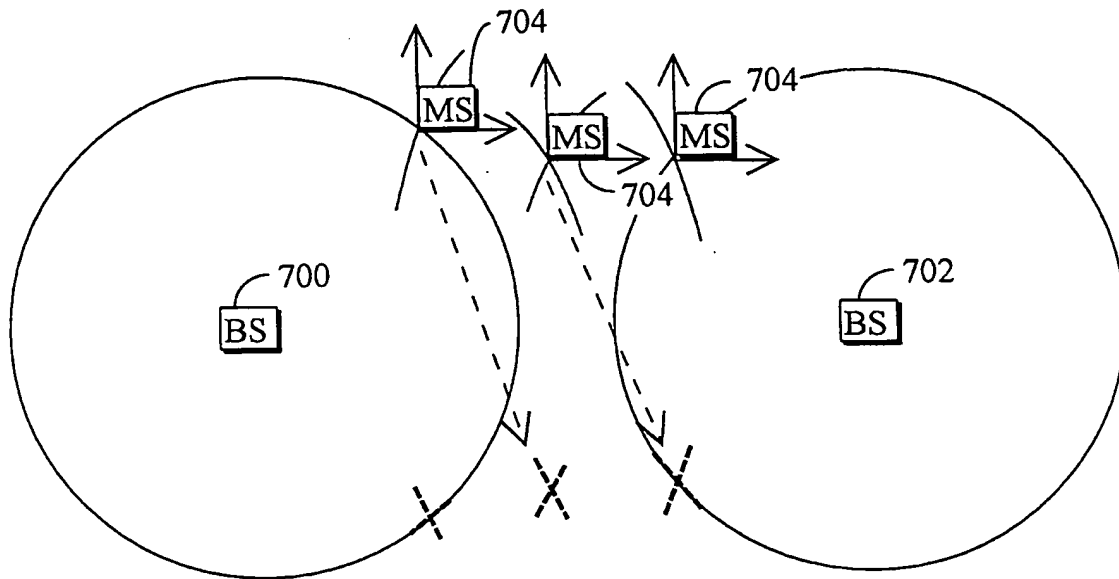


FIG. 7

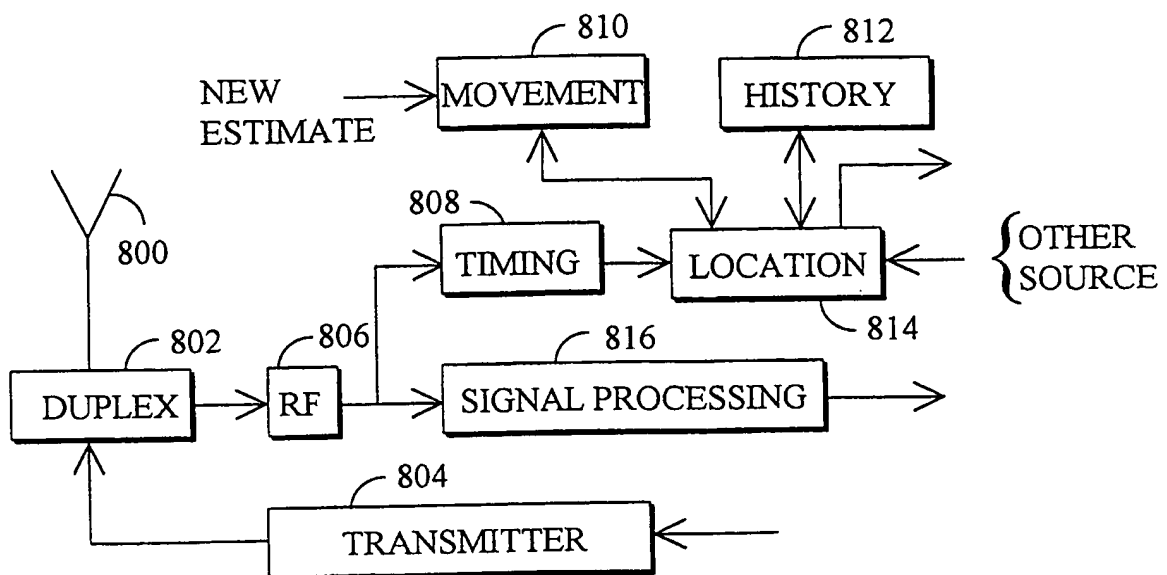


FIG. 8A

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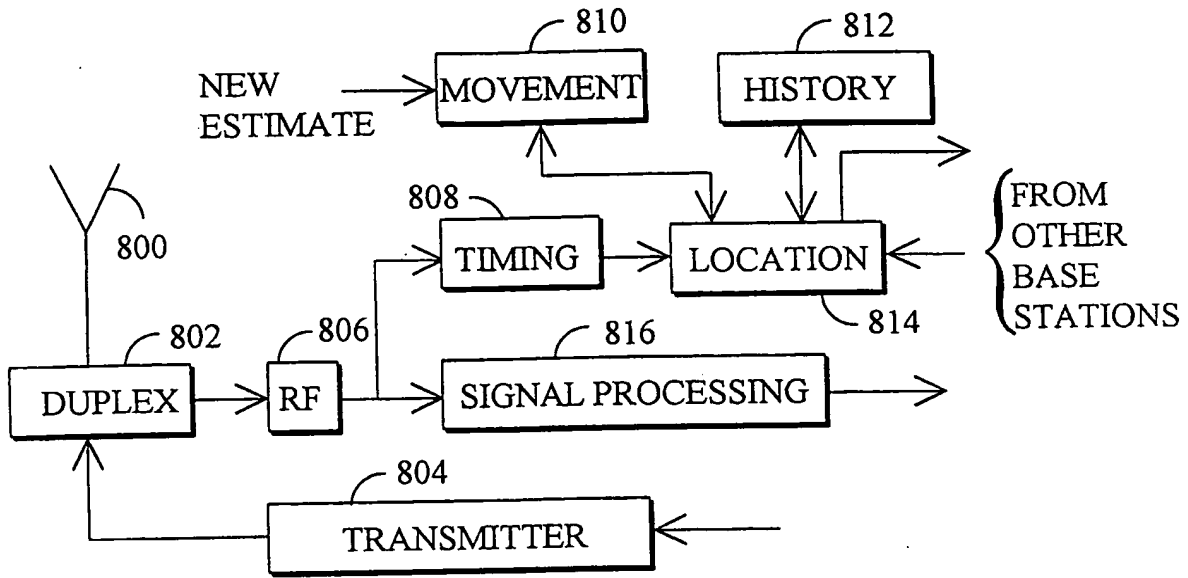


FIG. 8B

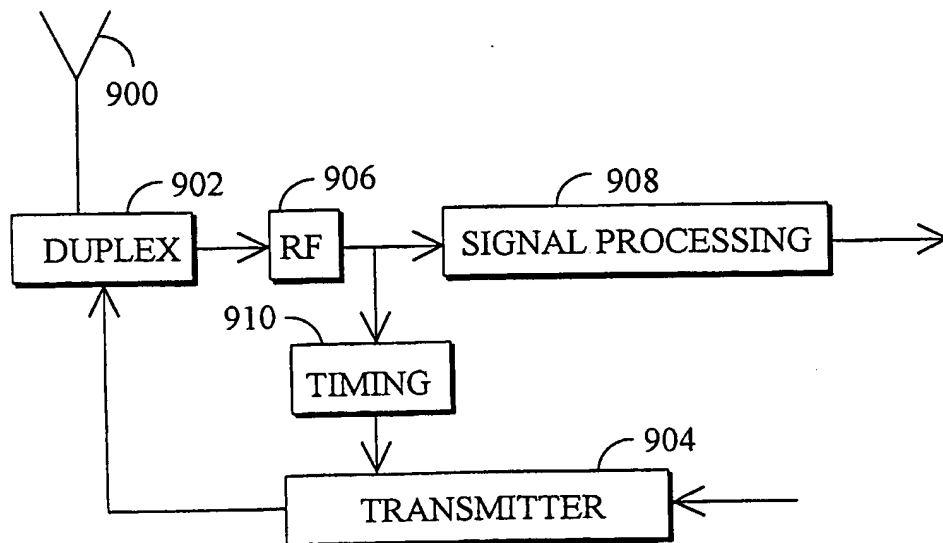


FIG. 9

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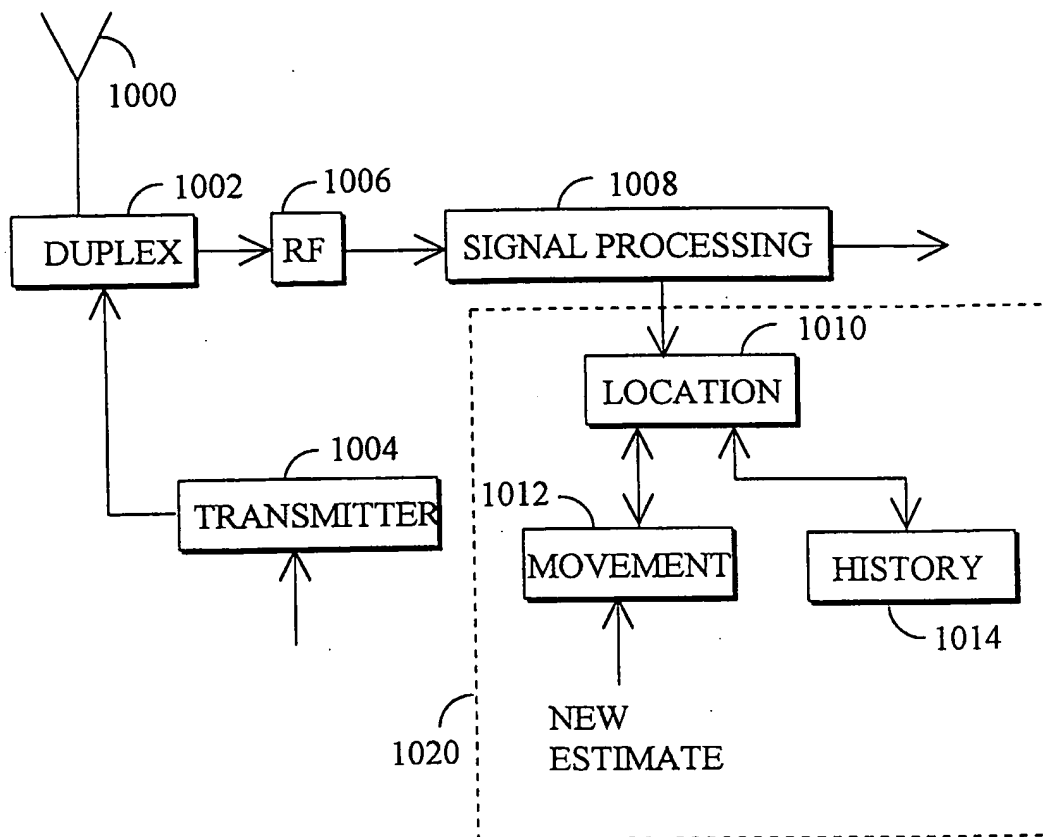


FIG. 10